



Future economic of concentrating solar power (CSP) for electricity generation in Egypt



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ABSTRACT

Population growth and economic development are leading to a continuous increase in energy demand in Egypt. At the same time conventional energy sources are diminishing amid growing global concern for the environment. These factors underline the importance of increasing the use of Renewable Energy sources. Egypt has enormous potential in Solar energy (CSP). There is sufficient proof of Egypt's potential for extracting energy from Concentrated Solar Power, especially power on demand generation. CSP represents a reliable and sustainable source of energy for Egypt with different outputs that can be used.

In this paper, we present a road map strategy for the market introduction of CSP in Egypt, removing the main barriers for financing and starting market introduction in the peak load and the medium load segment of power supply.

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Contents

1. Introduction	1120
2. Methodology	1120
3. Egypt fuel vs. international	1120
4. Solar energy in Egypt	1120
5. Current CSP technologies for power production	1121
6. Global concentrating solar power	1122
6.1. Global cumulative installed CSP capacity	1122
6.2. Deployment beyond 2030	1122
6.3. Electricity consumption	1122
7. Levelised cost of electricity generation	1123
8. Perspective and barriers for CSP	1124
9. A strategy for CSP finance in Egypt	1124
9.1. Parameter for calculate LCOE	1124
9.1.1. Assuming the electricity output per segment	1124
9.1.2. Cost of fuel (CoF)	1124
9.1.3. Investment cost of a conventional power plant	1125
9.1.4. Operation and maintenance cost	1125
9.2. LCOE for conventional power in Egypt	1125
9.3. LCOE in Egypt- CSP vs. conventional power	1126
9.4. Time-frames for cost competitiveness	1126
10. Conclusion	1126
Appendix A. The LCOE estimation follows the following calculations	1127

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Appendix B.	1127
Appendix C.	1127
Reference.	1127

1. Introduction

Energy is one of the most basic and crucial elements upon which to base a life and an economy nowadays. Energy is needed for daily tasks. Egypt is a country with high energy demand growth rate exceeding 6% [1].

Due to the rapid depletion of conventional energy resources, such as natural gas, and increased energy demand, conventional primary energy resources in Egypt will be unable to satisfy demand by 2020 [2]. To avoid this situation, the government should adopt two strategies: reduce demand and increase supply. In this context Renewable Energy and Energy Efficiency is particularly relevant. Renewable Energy addresses the supply of energy and guarantees environmental, economic and social sustainability in the energy sector. There are different types of Renewable Energy, such as solar, wind, biomass, and geothermal. Each type has its applications as well as advantages and disadvantages. A well balanced mix of them can secure the energy supply in the country and even replace conventional energy electricity. Moreover, Renewable Energy serves two key objectives: generating energy to meet demand and protecting the environment with emissions-free energy. Energy Efficiency addresses the need for a reduction in the demand for electricity by achieving the maximum utilization of generated energy while reducing waste.

Renewable Energy and Energy Efficiency are considered “the main pillars of environmental compatibility” [3]. Egypt has great potential for the use of solar power due to long sun duration hours, few cloudy days, low rainfall and high-constant sun radiation. With a potential of 73,000 TWh/year, Egypt is considered one of the countries with the highest potential for solar power not only in the Middle East but worldwide. The potential of Concentrated Solar Power (CSP) is of special importance, as Egypt is one of the sun-belt countries with high Direct Normal Irradiance (DNI) [3]. The use of solar power is not new to Egypt. In 1913, the first CSP experience took place in Maadi-Cairo. Frank Shuman designed a system to provide irrigation from the Nile to a surrounding desert area [4,5]. While this potential was discovered in the last century, it unfortunately was not further utilized. It is noteworthy that with solar power the country could generate enough electricity to satisfy domestic demand as well as that from Europe, the Middle East and North Africa (EUMENA), as well as worldwide.

2. Methodology

CSP power generation can help Egypt meet their sustainable development goals through provision of access to clean, secure, reliable and affordable energy. This paper explains removing the main barriers for financing and starting market introduction in the peak load, the medium load and base load segment of power supply.

This paper aims to obtain a range of data sources with the objective of developing visualize to comparison the CSP technologies and levelised cost of electricity with that conventional source. Conventional energy sources are limited and will gradually be depleted, which will create a shortage in supply in the near future. This could be resolved by decreasing demand through energy efficiency. To fill the remaining gap in supply, alternative

energy sources must be found which will be most likely be Renewable Energy sources.

This paper presents a strategy for the market introduction of concentrating solar power (CSP) plants in Egypt. In the first section, the paper explains the need of Egypt for sustainable supply of electricity and calculates the cost of electricity for Egypt model case. In the second part, the cost development of concentrating solar power plants is calculated on the basis of expectations for the expansion of CSP on a global level.

The research methodology was based on the review of previous papers and studies as well as published reports by local governmental authorities in Egypt such as the New and Renewable Energy Authority (NREA), the Egyptian Electric Holding Company (EEHC), National Research Center (NRC) international organizations concerned with Renewable Energy in general and others specialized in CSP.

3. Egypt fuel vs. international

The prices of energy used globally in 2010 was \$ 2.88/million - Btu for natural gas and 2.98 LE/ton of heavy fuel oil and (5.17 U.S. dollars/liter) for light fuel oil. There will be a gap if compared Egypt fuel prices with fuel world prices as shown in the following Table 1 [6].

Taking this forecast into consideration, the study will develop a scenario for CSP future energy production during peak load days (Fig. 1). Renewable Energy, especially CSP, will play a significant role in energy production while fuel will play a very small part.

4. Solar energy in Egypt

This study refers to evaluate the potential of Renewable Energy resources, especially CSP, according to technical and economic potential. The technical potential represents “the potential that can be accessed for power generation by the present state of the art technology” [6]. The “economic potential represent are those with a sufficiently high performance indicator that will allow new plants in the medium and long term to become competitive with other renewable and conventional power sources, considering their potential technical development and economies of scale” [6].

Solar Energy is a key energy source but it is distributed unevenly worldwide. Fig. 2 shows which areas of the world have highest potential for CSP, and demonstrates why Egypt is

Table 1
Egypt fuel prices compare international prices.

Fuel		Year				
		2010	2015	2020	2025	2030
NG Egypt	Million/m ³	2.88	2.91	3.12	3.57	4.30
NG World	Million/m ³	7.19	6.60	6.93	7.47	7.98
NG Gap		4.31	3.69	3.81	3.90	3.68
HFO Egypt	Million/Ktons	2.98	3.01	3.22	3.69	4.44
HFO World	Million/Ktons	3.37	3.45	3.56	3.62	3.90
HFO Gap		0.39	0.44	0.34	(0.07)	(0.54)
LFO Egypt	Million/Ktons	5.17	5.23	5.60	6.41	7.72
LFO World	Million/Ktons	13.69	14.01	14.46	14.70	15.84
LFO Gap		8.51	8.78	8.85	8.29	8.12

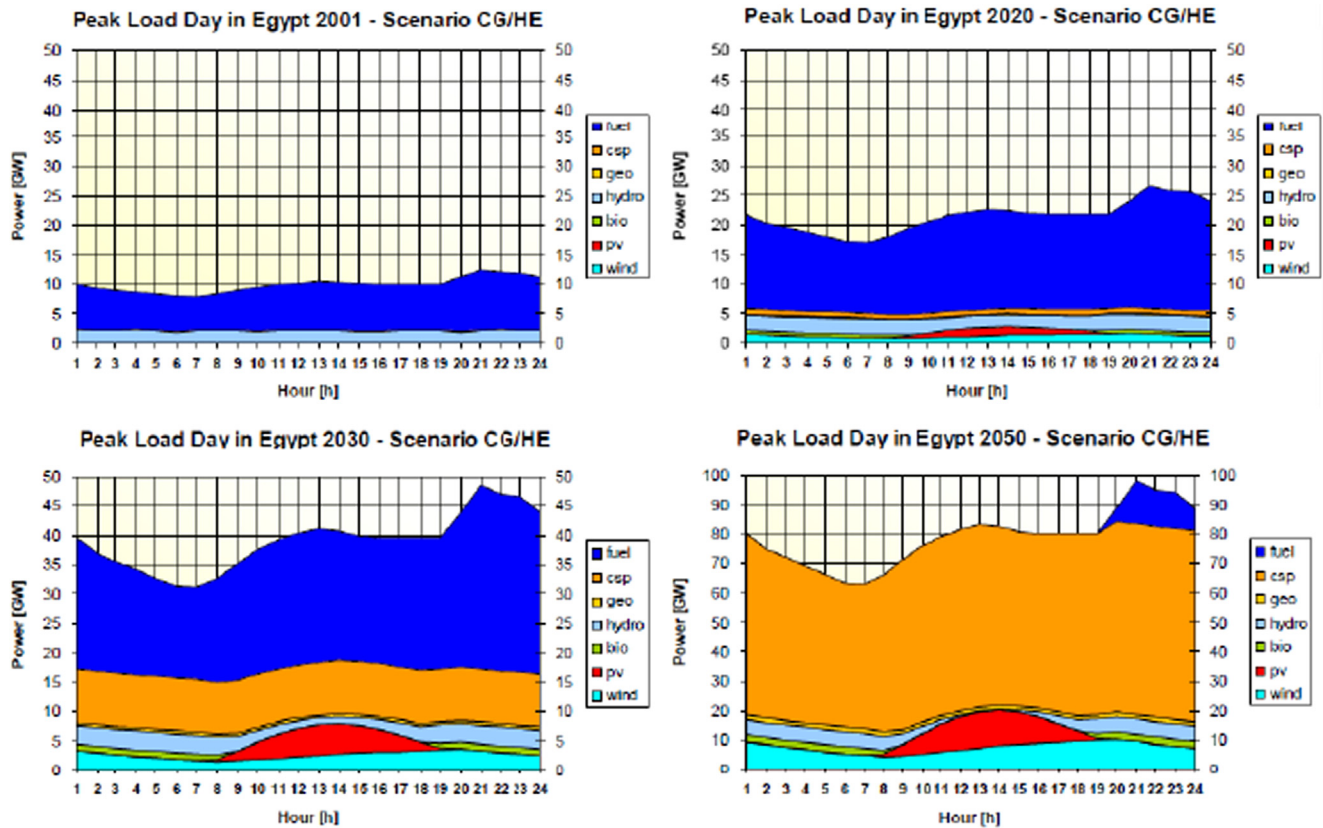


Fig. 1. Power generation on the peak load day in Egypt in 2001, 2020, 2030 according to the MED CSP scenario.

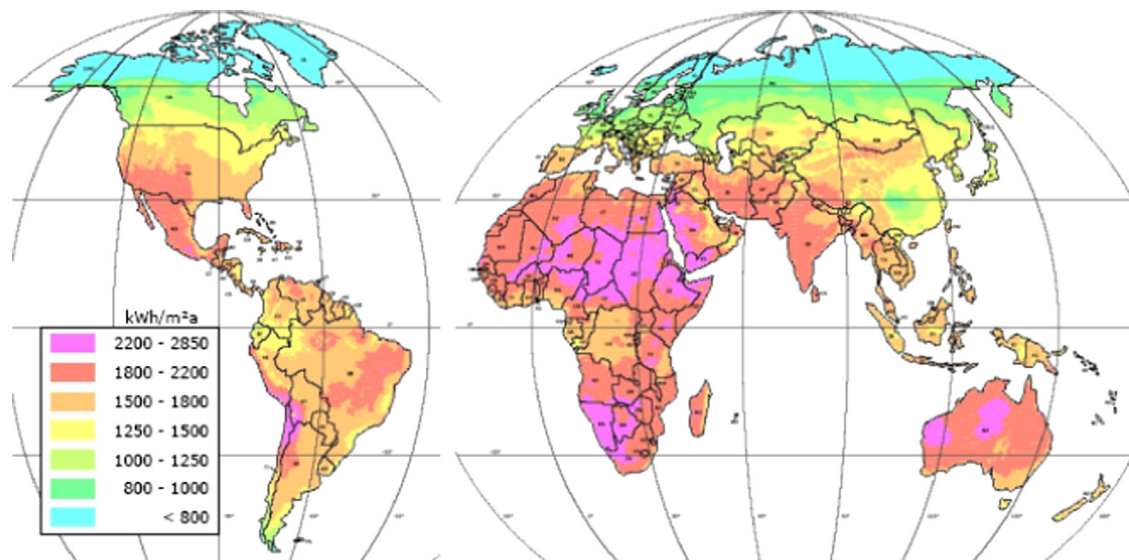


Fig. 2. Map of World Exposure to Direct Normal Irradiance (DNI) kWh/m²/year [7].

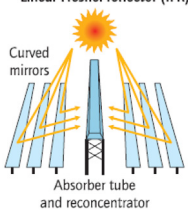
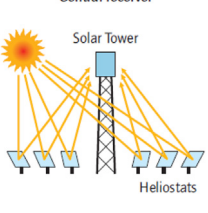
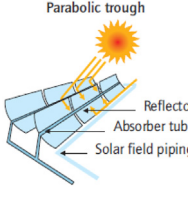
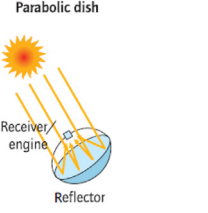
considered one of the Sun Belt countries. CSP technology depends on direct-beam irradiation, and its maximum benefit is thus restricted to high direct normal irradiance (DNI) areas.

Egypt belongs to the global sun-belt. Country's geographical position is advantageous with solar energy. In 1991 solar atlas for Egypt was issued indicating that the country enjoys 2900–3200 h of sunshine annually with annual direct normal energy density 1970–3200 kWh/m². (Fig. 2) and technical solar-thermal electricity generating potential of 73.6 Petawatt hour (PWh).

5. Current CSP technologies for power production

CSP produces electricity by converting solar energy into high temperature heat using diverse mirror configurations. The heat is then used to produce electricity through a conventional generator system using turbine. Currently, research is undertaken on various CSP technologies for varying levels of high temperature generation capabilities and conforming high thermodynamic efficiencies. At present, there are four main CSP technology families, which

can be categorized by the way they focus the sun's rays and the technology used to receive the sun's energy as follows.

	Focus type	Line focus	Point focus
	receiver type	Collectors track the sun along a single axis and focus irradiance on a linear receiver. This makes tracking the sun simpler.	Collectors track the sun along two axes and focus irradiance at a single point receiver. This allows for higher temperatures.
Fixed	Fixed receivers are stationary devices that remain independent of the plant's focusing device. This eases the transport of collected heat to the power block.	Linear fresnel reflectors 	Towers (CRS) 
Mobile	Mobile receivers move together with the focusing device. In both line focus and point focus designs, mobile receivers collect more energy.	Parabolic troughs 	Parabolic dishes 

This paper will develop a concept proposing a strategy for management CSP in the Egypt. This will be applied in three steps. First is calculating the cost of generating power from conventional sources and its development in the future. Then will be followed by identifying the cost of CSP and its development in the future due to the economies of scale after its projected expansion.

6. Global concentrating solar power

6.1. Global cumulative installed CSP capacity

Spain and the US dominate the market, with 69% and 28% of installed capacity respectively, US used to be the only actor in CSP until 2007 when Spain built its first plant (PS10).

- Spain then successfully developed 1.9 GW of CSP and now dominates the market with 69% of global installed capacity.
- Middle Eastern and African countries have commissioned 65 MW between 2010 and 2011 in Algeria, Morocco and Egypt. A additional 100 MW plant came on line in March 2013 in the UAE (Shams 1).

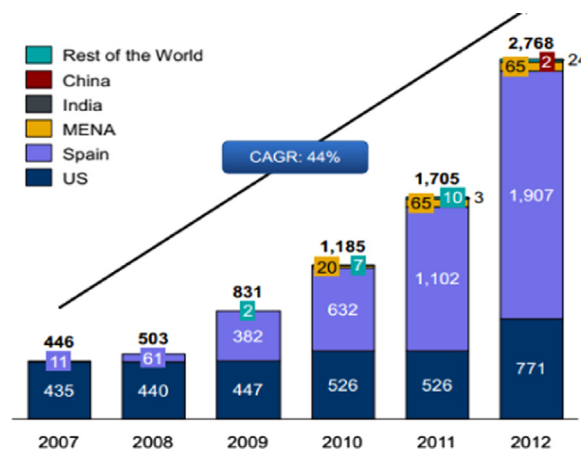


Fig. 3. Global Cumulative Installed CSP capacity, MW, 2007–2012 [8].

- China and India have started to show interest in CSP technology since 2010, with respectively 1.5 MW and 2.5 MW of capacity installed at the end of 2012 (Fig. 3).
- Plants with nominal capacities of 1 MW to 9 MW have also been developed in Australia, Thailand, France, Italy, and Germany.

6.2. Deployment beyond 2030

By 2040, the global installed CSP capacity reaches 715 GW, with an average capacity factor of 45% (3900 h/year), thereby providing 2790 TWh annually. The solar share of 85%, or 2370 TWh, represents 8.3% of global electricity generation [9].

By 2050, the global installed capacity reaches 1089 GW, with an average capacity factor of 50% (4380 h/year), thereby providing 4770 TWh annually, or 11.3% of the estimated global electricity production in the IEA publication Energy Technology Perspectives (ETP) 2008. As the global electricity system becomes decarbonized, biogas and solar fuels become the main source of backup and hybridization in CSP plants from 2030 to 2050. There is thus no greater reason than before to attempt to build solar-only plants. Therefore, the roadmap foresees the same solar share of 85% or 4050 TWh in 2050, representing 9.6% of global electricity production.

Fig. 4 shows where CSP electricity will be produced and consumed by 2050. North America would be the largest producing region, followed by Africa, India and the Middle East. Africa would be by far the largest exporter, and Europe the largest importer. The Middle East and North Africa considered together, however, would produce almost as much as North America (the United States and Mexico). Indeed, the Middle East–North Africa region is the largest producer when all solar products are considered, including gaseous and liquid fuels [7].

6.3. Electricity consumption

The DLR (German Aerospace Center) has produced detailed studies on forecasted electricity consumption for Egypt up until 2050. This is due to an expected population increase as well as the expected economic growth, which has a proportional relationship to the electricity demand. This increase cannot be met by conventional energy sources, so the government will need to rely on Renewable Energy sources. Topping the list of these Renewable Energy sources is CSP, upon which Egypt will largely depend to satisfy the electricity demand (Figs. 5 and 6). Egypt shall target a share of 30% in year 2020 and will reach 55% in year 2050 [6].

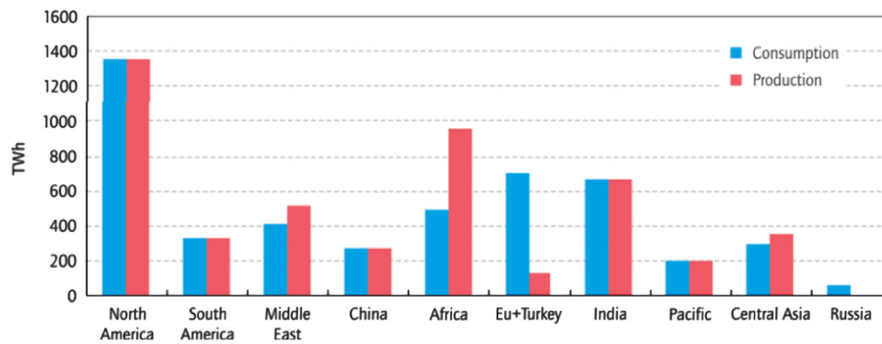


Fig. 4. production and consumption of CSP electricity by 2050 (in TWh) [10].

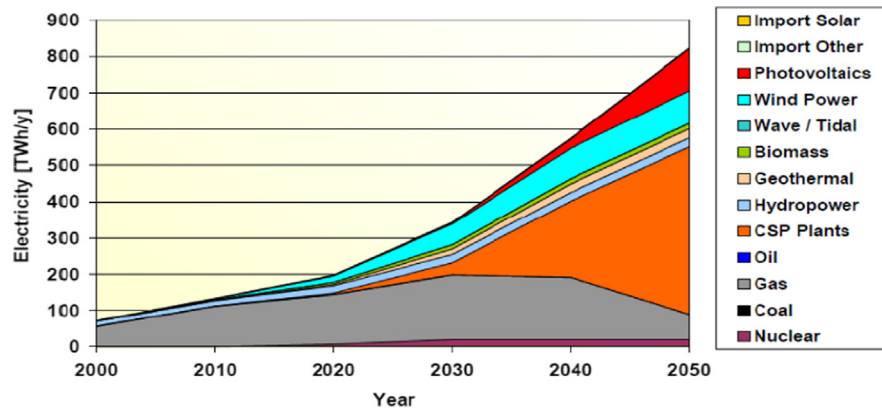


Fig. 5. Electricity scenario by primary energy sources for power generation in Egypt [6].

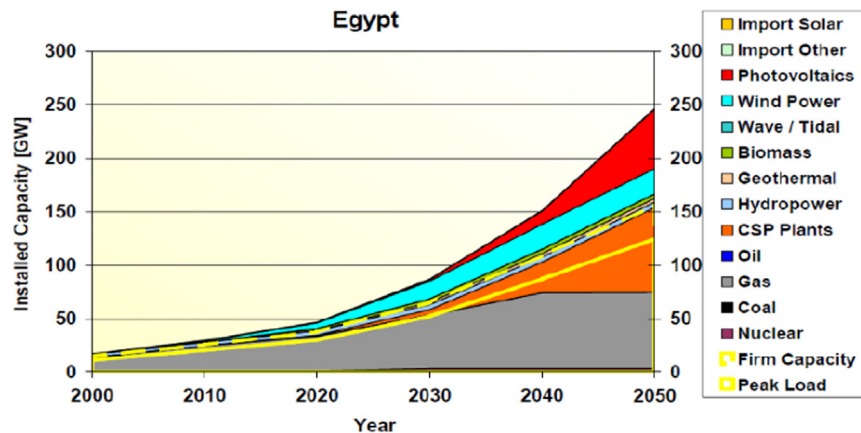


Fig. 6. Installed capacity required for the electricity supply in Egypt [6].

7. Levelised cost of electricity generation

The most important parameters that determine the 2011/ 11–The levelized cost of electricity (LCOE) of CSP plants are:

- The initial investment cost, including site development, components and system costs, assembly, grid connection and financing costs;
- The plant's capacity factor and efficiency;
- The local DNI at the plant site;
- The Operation and Maintenance of annual operation and insurance [\$ /y] (O&M) costs (including insurance) costs; and
- The cost of capital, economic lifetime, etc.

The economics of CSP and other renewable technologies are, with the exception of biomass, substantially different from that of fossil fuel power technologies. Renewable have, in general, high upfront investment costs, modest O&M costs and very low or no fuel costs. Conventional fossil fuel power tends to have lower upfront costs and high (if not dominant) fuel costs, which are very sensitive to the price volatility of the fossil fuel markets. In contrast, renewable technologies are more sensitive to change in the cost of capital and financing conditions.

It is important to note that the LCOE of CSP plants is strongly correlated with the DNI. Assuming a base of 2100 kWh/m²/year (a typical value for Spain), the estimated LCOE of a CSP plant is expected to decline by 4.5% for every 100 kWh/m²/year that the DNI exceeds 2100 (Fig. 7).

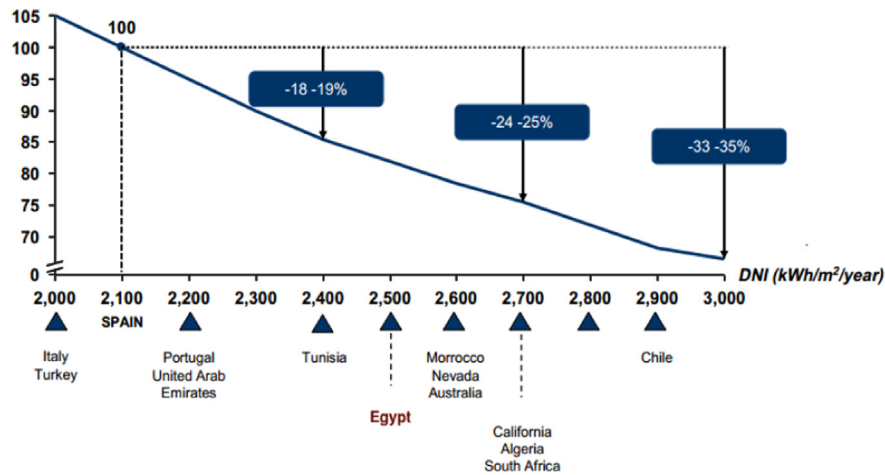


Fig. 7. The LCOE of CSP plants as a function of DNI [11].

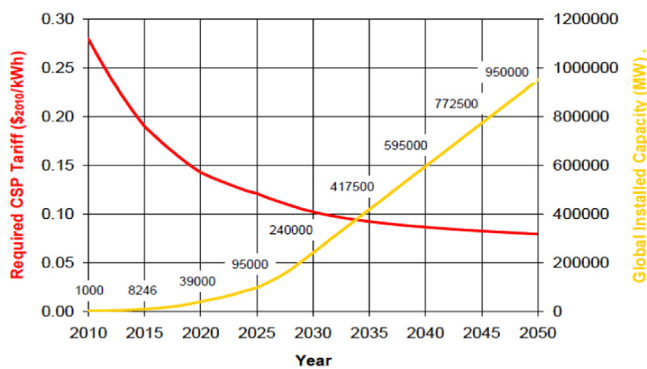


Fig. 8. Expansion of globally installed CSP capacity and resulting reduction of required tariff for the model parameters shown in Table 2.

In Egypt, The estimated average value of the DNI around 2500.

8. Perspective and barriers for CSP

CSP is a promising technology in this context because its resource potential in Egypt is rather high and the plant configuration is similar to that of a conventional power plant, which can be adapted to any load segment. CSP capacity expansion perspectives and cost learning curves from different sources were taken as a basis for the modeling of the levelized cost of electricity (LCOE) of concentrating solar power plants. The present feed in tariff in Spain is 27 €/ct/kWh, which has proven to be sufficiently high to trigger considerable investment in CSP. We will use this as a reference value for successful market in 2010–2011 and define an equivalent value for MENA region in US\$ currency. Assuming an exchange rate of 1.19 \$/€ and a reference direct normal irradiance in Egypt of 2500 kWh/m²/a compared to a typical DNI in Southern Spain of 2090 kWh/m²/a, our equivalent required tariff for CSP in our model case would be 28 USct/kWh in the year 2010 [12] (Fig. 8).

The CSP Technology Roadmap for Concentrating Solar Power of the International Energy Agency starts in 2010 with costs ranging from 20 to 30 US-ct/kWh and reaches 17–25 US-ct/kWh by 2013, depending on annual solar irradiance (IEA 2010) [13].

For the calculation of cost development of CSP in the future, we have taken expectations of global CSP expansion from different sources (IEA 2010, Greenpeace 2009, AT Kearney 2010). Expectations for CSP capacity expansion range from 2900 MW to

Table 2

Model parameters for installing CSP capacity.

Preference LCOE of CSP in 2010	\$/kWh	0.280
Preference direct normal irradiance	kWh/M ² /a	2400
CSP progress ratio	%	88.0%

29,000 MW by 2015, from 20,000 MW to 150,000 MW by 2020 and from 230,000 MW to 340,000 MW by 2030. Expectations for 2050 range from 850,000 MW to 1,500,000 MW of cumulated world-wide installed CSP capacity. In order to calculate cost reduction effects for our model reference case, we have selected a moderate global expansion scenario, reaching 8250 MW in 2015, about 39,000 MW in 2020 and 240,000 MW in 2030. This conservative guess will be the basis for our cost model scenario. In 2050 about 950,000 MW are assumed to be installed. The required tariff for CSP is reduced according to the world wide installed capacity, with a progress ratio of PR=0.88. A progress ratio of 0.88 means according to a model by Neij, that the cost is reduced by 12% every time the world wide installed capacity doubles [14].

Under these conditions the required tariff for CSP is reduced to 19 ct/kWh by 2015, 14 ct/kWh by 2020 and 10 ct/kWh by 2030. In the long term, a cost below 8 ct/kWh is achieved.

9. A strategy for CSP finance in Egypt

9.1. Parameter for calculate LCOE

9.1.1. Assuming the electricity output per segment

For this model, the electricity output per segment is needed, while only the value of total electricity output is known, which is 101,898 GWh/a [1]. From the reference model for MENA region, the share of each segment could be calculated and assumed to be the same distribution in Egypt. Multiplying this share by the total annual electricity output will give us the electricity output per segment as shown in Table 3 [1].

9.1.2. Cost of fuel (CoF)

The objective of the coming calculations is to determine the Cost of fuel for the different segments (peak-, medium, and base load). In the annual report of the EEHC a case was given that showed savings of 581 million EGP, when 3195 k toe were saved in the year 2008–2009, Specific Fuel Cost [EGP/toe] was 181.84

Table 3
Electricity output per segment in Egypt.

Study [15]	Egypt			
	Installed capacity [MW]	Electricity [GWh/a]	Share of Electricity	Electricity [GWh/a]
Peak load	1000	2000	5%	4852
Medium load	2500	10,000	24%	24,261
Base load	4000	30,000	71%	72,784
Total	7500	42,000	100%	101,898

according to the following equation:

$$\text{specific fuel cost [EGP/Toe]} = \frac{\text{fuel cos [EGP]}}{\text{fuel [ktoe]}} \quad (1)$$

With this value in mind, as well as knowing the total fuel consumed in conventional power generation in Egypt (22,179 k toe) [1], total electricity generation (101,898 GWh/a) [1], the Cost of Fuel [\$/MWh] (7.19) according to the following equation.

$$\text{Specific fuel cost [USD/MWh]} = \frac{\text{fuel consumption [toe]} \times \text{fuel cost [EGP/Toe]} \times [\text{USD/EGP}]}{\text{Electricity output [MWh]}} \quad (2)$$

This is the fuel cost for the base load, the one with the highest efficiency assumed to be $\eta=40\%$. The efficiency plays a significant role in the fuel consumption and thus the fuel cost. Therefore in order to estimate the cost of fuel for the medium- and peak load, with a fuel efficiency of 35% and 30% respectively, equation will be followed:

$$\text{COF}_{\text{medium/peak}} = \text{COF}_{\text{base}} \left[\frac{\eta_{\text{base}}}{\eta_{\text{medium/peak}}} \right] \quad (3)$$

where E: electricity generated per year (= installed capacity (kW) × annual full load hours (h/y)) [kWh/y], η : Efficiency [%].

This will result in a COF_{medium} of 8.22 USD/MWh and COF_{peak} of 9.59 USD/MWh.

9.1.3. Investment cost of a conventional power plant

The thermal plant investment cost is important to determine the LCOE. In Egypt there are three main types of power generation, Combined Cycle, Gas Turbines-, and Steam Turbine Power Plants. Knowing the installed capacity of each type, the share of the production can be calculated with the results. As well knowing the investment cost of each generation type, i.e. Combine Cycle 800 USD/kW, Gas 500 USD/kW and Steam 1400 USD/kW [16] then by multiplying these costs with the share of the installed capacity (35%, 8% and 57%) respectively. we calculate the weighted average for the thermal plant investment cost of 1114.77 USD/kW [16].

9.1.4. Operation and maintenance cost

The fixed O&M costs vary between the different types of generation, as Combined Cycle charge 2 USD/kW, Gas 13 USD/kW while the most expensive ones are the Steam Power Plants with 28 USD/kW. Using the weighted average according to the respective installed capacity (7178 MW, 1641 MW and 11,458 MW) respectively, the average fixed O&M cost could be calculated as 17.58 USD/kW/year [16].

9.2. LCOE for conventional power in Egypt

The resulting cost structure of our model case is shown in (Fig. 9) for the peak, medium and base load segments as well as for the resulting weighted average cost of electricity.

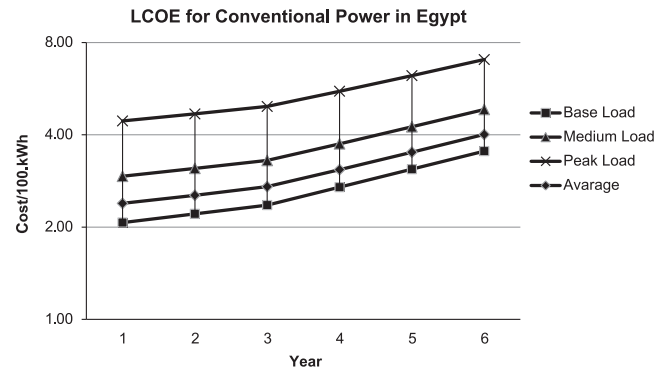


Fig. 9. LCOE for conventional power in Egypt.

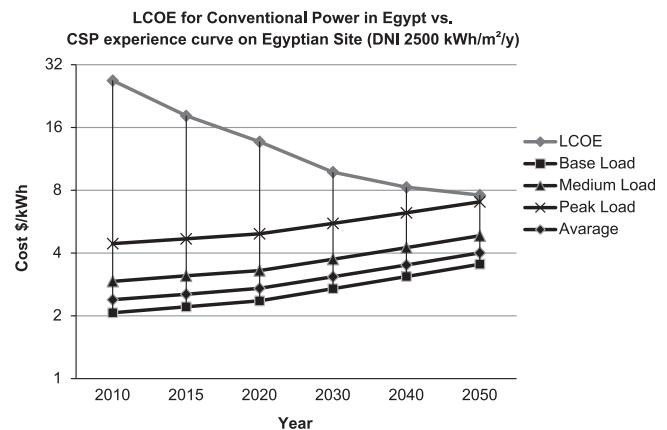


Fig. 10. LCOE in Egypt, CSP vs. Conventional Power.

Fig. 9. shows the LCOE calculated as in (Appendix A) for new plants including capital, operation and fuel for a business as usual case. Business as usual is defined by maintaining the electricity mix exactly as defined in Table 1 and applying a fuel cost inflation rate of 1.5% for the fuel mix required for power generation. Fuel cost escalation and fuel consumption of newly installed power capacity is especially relevant for quickly growing economies with high demand growth rates, as it will directly affect economic development in a negative way. For our model case, we have assumed a rather moderate 3.6%/a growth of electricity demand, while growth rates of over 7% per year.

The resulting cost structure for the new CSP plants in Egypt demonstrated in Fig. 9

In order to determine the value of the current specific investment (C_0) (See Appendix B) for Egypt, we need a reference country. Spain is one of the countries that has realized good progress in the CSP field in Europe and worldwide; therefore is a good indicator to estimate the specific cost in Egypt.

As previously illustrated in (Fig. 10), Egypt has a technical potential exceeding 2800 kWh/m²/y, while the new identified site

for the coming project (Kom Ombo) has an average DNI of 2500 kWh/m²/y [2]. Therefore this DNI value could be used as an indicator for the DNI in Egypt in this model. Spain with only a DNI level of 2090 kWh/m²/y (southern Spain) had a feed-in tariff of 27 ct€/kWh in 2010, which was sufficient to stimulate the CSP industry in Spain [4,6]. These data could be used for calculating (C₀) [6].

$$C_{0 \text{ Egypt}} = C_{\text{Spain}} \left[\frac{\text{DNI Spain}}{\text{DNI Egypt}} \right] \$/\epsilon \quad (4)$$

Accordingly C₀Egypt – assuming an USD to EUR exchange rate of 1.19 – is equal to 26.86 ct\$/kWh. (C₀Egypt = 26.86 ct\$/kWh), which is on the lower half of the worldwide estimated CSP costs by the IEA for 2010 of 20–30 ct\$/kWh [4]. The reason for this figure is that the cost depends on the annual solar radiation and Egypt is one of the countries with high DNI. Applying equation to the following data (Table 4), results to the CSP experience cost curve for Egypt, which decreases from 26.86 ct\$/kWh in 2010 to 7.58 ct\$/kWh in 2050 (Fig. 10).

9.3. LCOE in Egypt- CSP vs. conventional power

The CSP experience curve shows that CSP can be a significant component in the future electricity mix of Egypt. CSP can represent a hedge against the volatility of the fuel costs and external oil markets. Moreover it adds to the economical development of local industries and aggregate economic development of the country, as well as having environmental advantages

Egypt is one of the countries with high increase in electricity demand exceeding 6% per year [1]. Moreover the experienced electricity outages in summer 2010, will force the installation of new capacities. Accordingly it is expected during the coming years to increase the investments in power plants installations. This could represent an opportunity for CSP. (Fig. 6), will allow us to compare between the LCOE of the CSP and the conventional power plant for the different segments. As shown in the figure, the CSP cost is decreasing significantly, however this decrease does not allow it to be economically competitive with the cost of the electricity from conventional source. The main reason behind this case is the extremely low fuel prices available in Egypt (because of the energy subsidy).

9.4. Time-frames for cost competitiveness

An alternative approach to estimate future potential for cost reduction is to use well-estimating “learning curve” effect, which are based on observations for technologies more generally that their cost reduces by a characteristic percentage for each doubling of installed capacity (hence, the “learning rate” is defined as the percentage reduction in cost for each doubling of installed capacity). Although this concept was originally applied to product of a single entrepreneurial entity it has been found to work for many mass produced components on the global scale.

Trib (2004) has suggest an approach that combines different learning rates of components and the effects of scaling to larger plants of CSP, and calculated a CSP system learning rate of 14%. The uncertainty in this figure is high as it is not based on empirical data. The following analysis, which examines cost reduction up to 50%, therefore considers a range of 10–20% as potentially

Table 4
LCOE for CSP in Egypt parameters.

CSP Progress ratio [15]	0.88
Reference DNI for Egypt [kWh/m ² /y]	2500
Reference LCOE for CSP in Egypt in 2010 [ct\$/kWh]	26.86

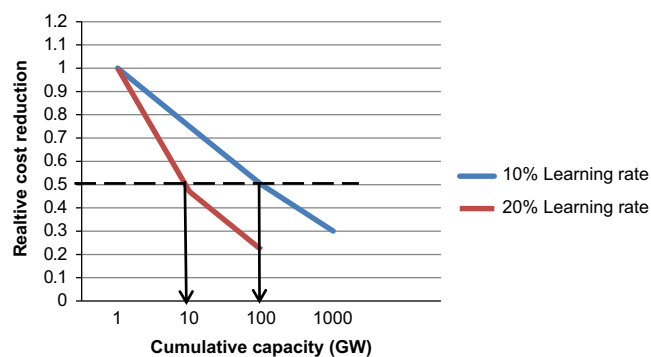


Fig. 11. Relative of CSP technology as a function of the cumulative installed capacity for learning rates of 10 and 20%.

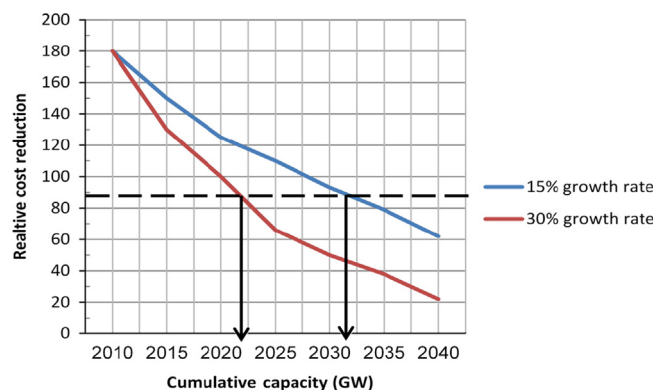


Fig. 12. Development of LEC over time for CSP systems installed at 15% (low) and 30% (high) growth rates per year (based on a learning rate of 15%).

achievable for CSP. The impact of installed capacity on cost for this range of learning rates is illustrated in (Fig. 11) [16]. Starting from an actual installed capacity of 1 GW, a 20% learning rate would require an installed capacity of around 9 GW to halve costs, whereas 100 GW would be required in the case of a 10% learning rate [17].

Fig. 12 illustrates the potential implications of a learning rate of 15%, i.e. in the middle of this range, for when CSP may reach a 50% cost reduction. Starting from a current CSP installation rate of around 500 MW per year, and assuming a growth rate in CSP installations of 15% (low) and 30% (high) per year, results in CSP achieving a 50% cost reduction between 2021 and 2031 [16].

The learning rate and the growth rate of installed CSP capacity are key determinants of when CSP will be cost competitive are key determinants of when CSP will be cost competitive with other technologies. the ranges of figures selected in this analysis are based on expert estimates and opinion, and have not been verified by actual data (which are not available) it is therefore strongly recommended that mechanisms are put in place that enforce a transparent monitoring of installation costs, and the rate of CSP technology capacity of the learning rate to be refined.

The growth rate of the CSP market is currently constrained by market. Opportunities rather than production capacity. Additional incentives, and the creation of new market opportunities in other countries, will help to speed up the cost reduction process according to this model (Appendix C) (Fig. 12).

10. Conclusion

Egypt's impressive CSP potential exceeds 73000 TWh/year – one of the highest in the region. Other promising characteristics

are a high DNI (1970–3200 kWh/m²/year), high sun duration hours (9–11 h), few cloudy days, large expanses of unoccupied desert land, and an extended national electric grid. All these factors make Egypt a perfect location for CSP projects worldwide. It is expected that CSP will become a striking contributor to the Egyptian electric and water supply in the medium term. CSP is the most important future power source for Egypt as it has the highest potential of all the Renewable Energy sources. Because of this, it deserves government efforts to promote and encourage investment in this technology. In the five-year plan to implement the Egyptian Energy Strategy (2012–2017), 100 MW of CSP are planned. This is a small target compared to its huge potential, but it is a good first step.

More attention should be given to CSP by creating a special sub-authority to promote this sector. This entity could prepare DNI measurement campaigns, identify specific sites for CSP power plants and prepare feasibility studies. They would also allocate and acquire land for projects, provide technical support, identify business partners.

Appendix A. The LCOE estimation follows the following calculations

$$LCOE = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

Where

LCOE=the average lifetime levelised cost of electricity generation; I_t =investment expenditures in the year t ; M_t =operations and maintenance expenditures in the year t ; F_t =fuel expenditures in the year t ; E_t =electricity generation in the year t ; r =discount rate; and n =life of the system.

Appendix B

The cost experience curve function is

$$C_x = C_0 \left(\frac{P_x}{P_0} \right)^{\log PR / \log 2}$$

[6,10]

where PR: progress ratio, C_x : specific investment at point x , C_0 : specific investment at reference point 0, P_x : cumulated capacity at point x , P_0 : cumulated capacity at reference point 0

Appendix C

For Figures Growth rate [15].

The cumulative installed capacity, CAP(y) at a given year, y is given as:

$$CAP(y) = CAP(0) (1 + r_c)^y$$

where CAP(0) is cumulated installed capacity at present and r_c is growth rate factor (-).

Cost reduction.

The electricity cost at a given installed capacity, LEC(CAP), reduces by learning rate factor r_l

(-) per doubling of CAP;

$$LEC(CAP) = LEC(0) (1 - r_l)^{2 \log [CAP/CAP(0)]}$$

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